Lecture 12 - Control of WECS and practical experience with the Wavestar WEC

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Wavestar – a short introduction

PhD course

"Numerical and experimental modelling and control of Wave Energy Converters"

Tuesday 1 September 2015

Location: Ecole Centrale Nantes, Nantes, France

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AALBORG UNIVERSITY

WAVESTAR

How did we get there in the wind sector?

Learning is hard…

Testing is essential!

WAVESTAR

Wave Star A/S

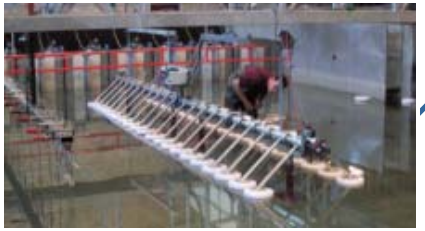
Key features

- **Established** in 2003 in Denmark
- **12 years** of R&D / **€34M** invested (Clausen family)
- **Multi point** absorber technology
- **One of the most advanced** digital hydraulic system
- **Operational** prototype from Sept. 2009 to Sept. 2013
- **A reliable, secured and efficient** device
- **Maturity level**: Pre-commercial

Technology / Stages of development

Various prototypes

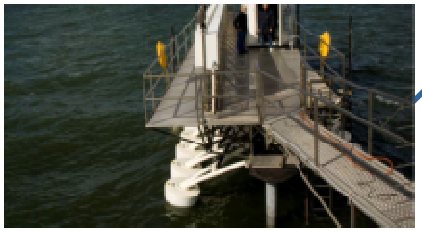
2004 - 2005



Aalborg University

- Scale **1/40**
- Float diameter: 0.25 m

2006 - 2010



Nissum Bredning

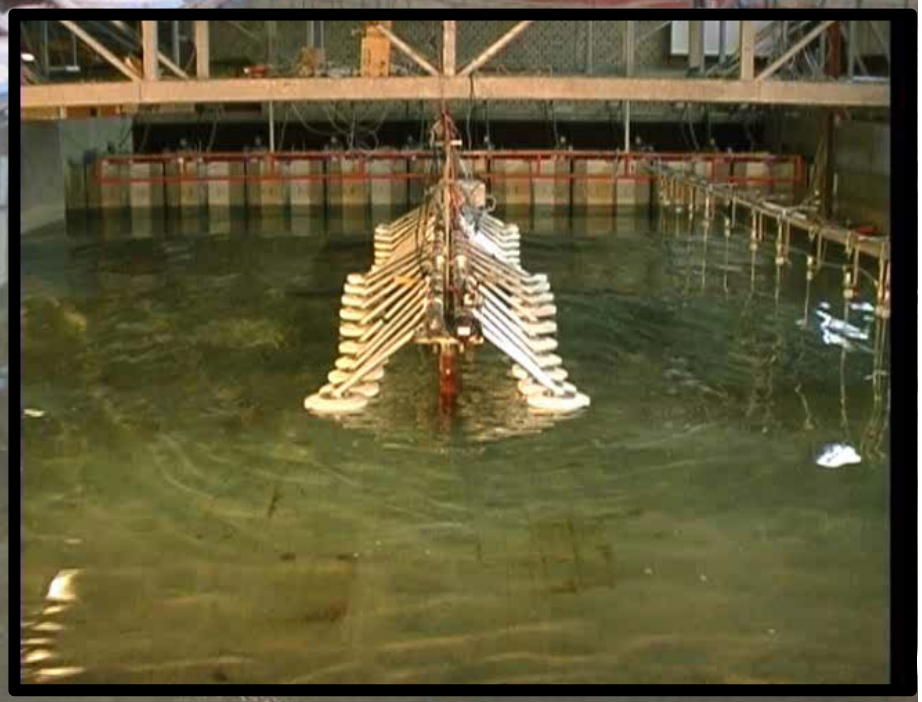
- Scale **1/10**
- Float diameter: 1.0 m

2009 - 2013

Hanstholm

- Scale **1/2**
- Float diameter: 5 m
- Number of floats: 2

Wavestar scale 1:40
Aalborg University, Denmark



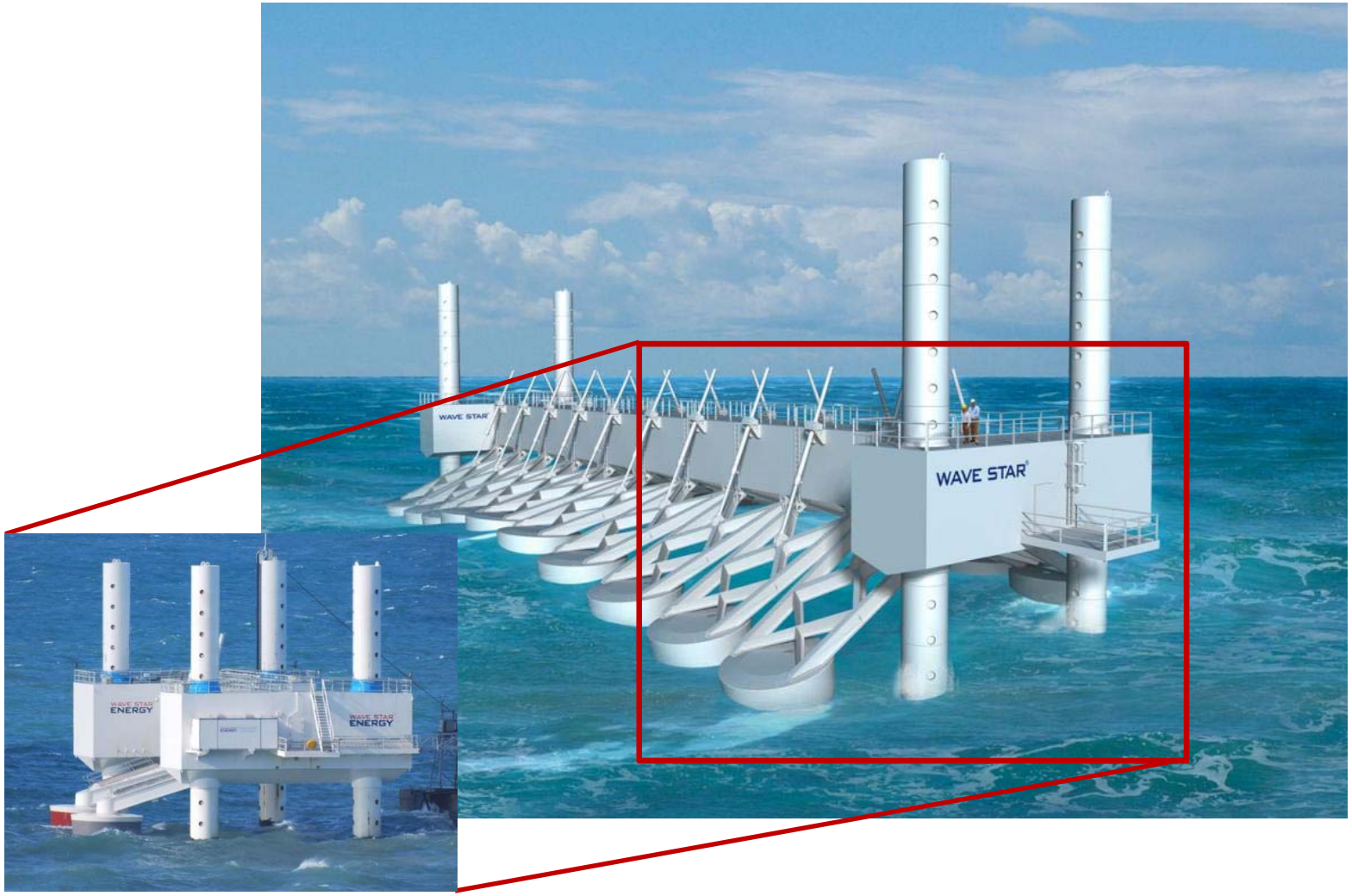
Wavestar scale 1:10
Nissum Bredning, Denmark


Normal operation


Storm protection mode

More than 4 years in operation

The demonstrator at Hanstholm is a section of the complete machine

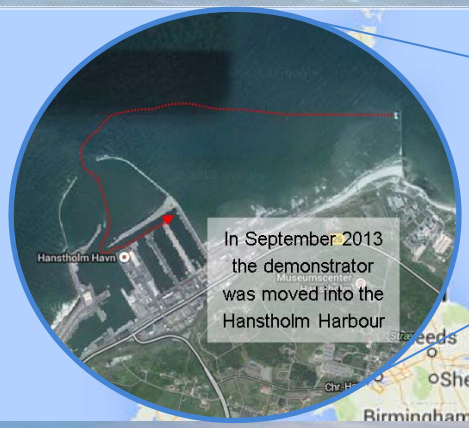


The Wavestar demonstrator tour

4 years of operation at site

Installation by Roshage Pier in September 2009

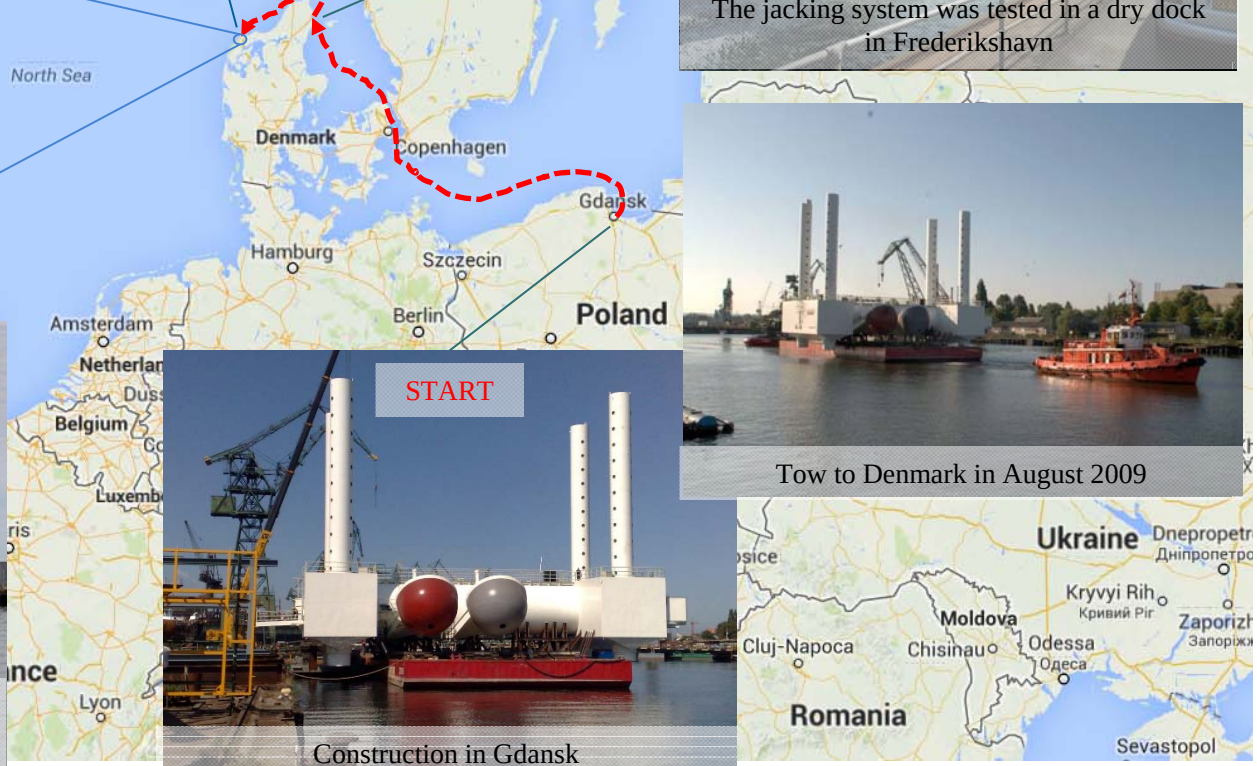
The jacking system was tested in a dry dock in Frederikshavn

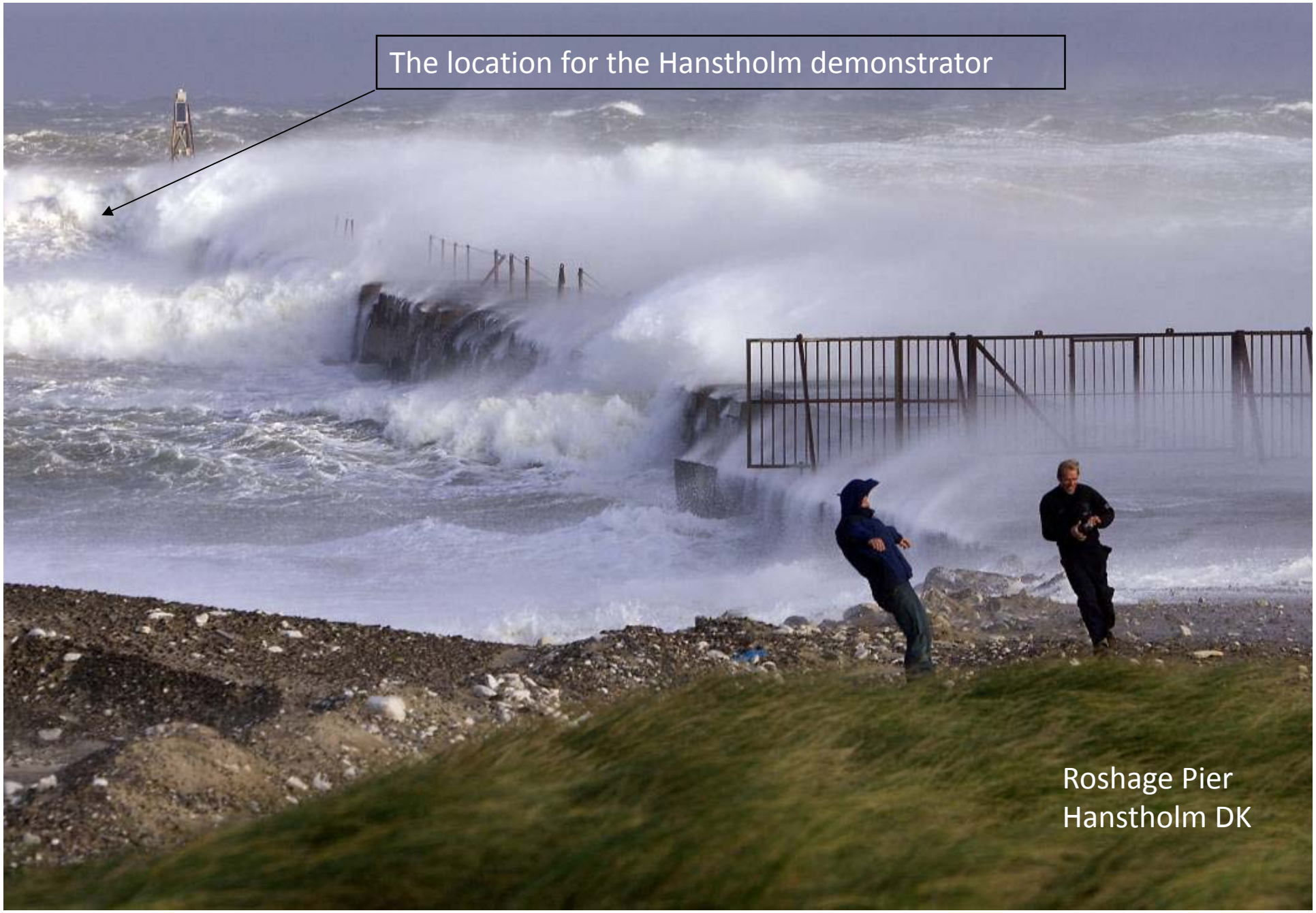


Tow to Denmark in August 2009

The demonstrator will be inside Hanstholm Harbour to be upgraded in 2014-2015

Construction in Gdansk




The location for the Hanstholm demonstrator
Roshage Pier
Hanstholm DK

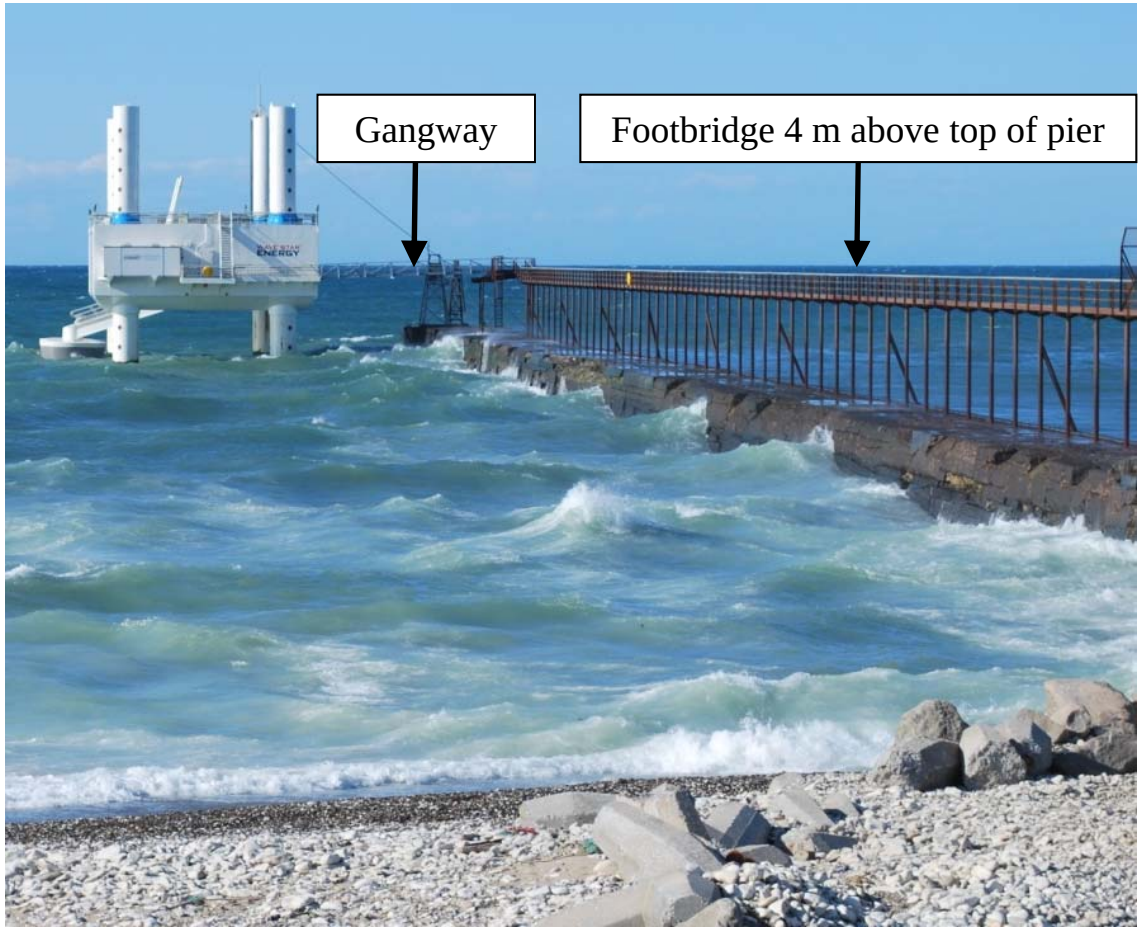
10


The demonstrator was built in Gdansk in Poland
and towed to Denmark in August 2009


The jacking system was tested in a dry dock in Frederikshavn, Denmark

12

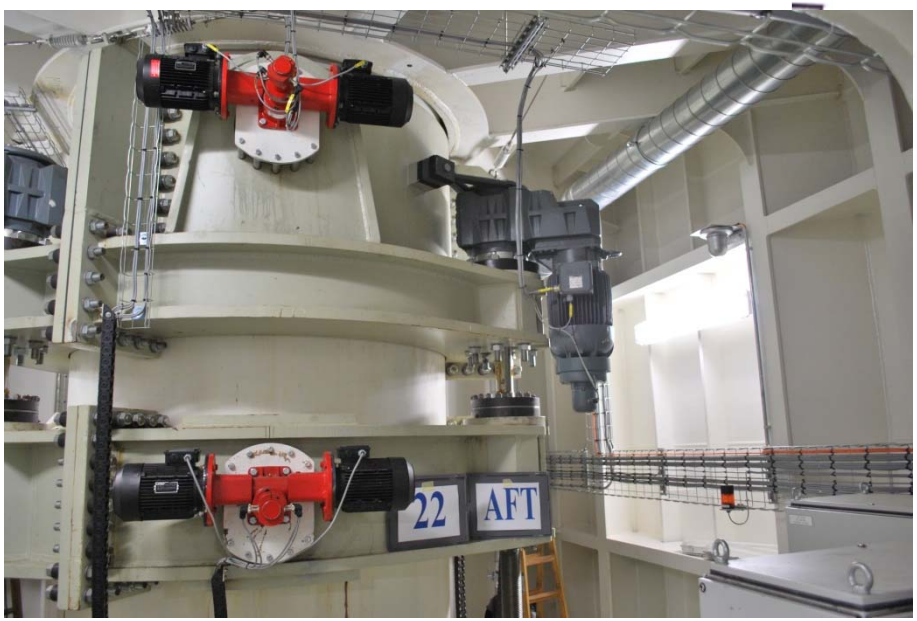
The Wavestar demonstrator was installed from a barge in September 2009 and it was accessible in any weather via a 300 m long access bridge



The demonstrator at Hanstholm

The 19th of September 2009 the installation was finalized and the machine was placed in storm protection

Details inside



Jacking system and hydraulic system

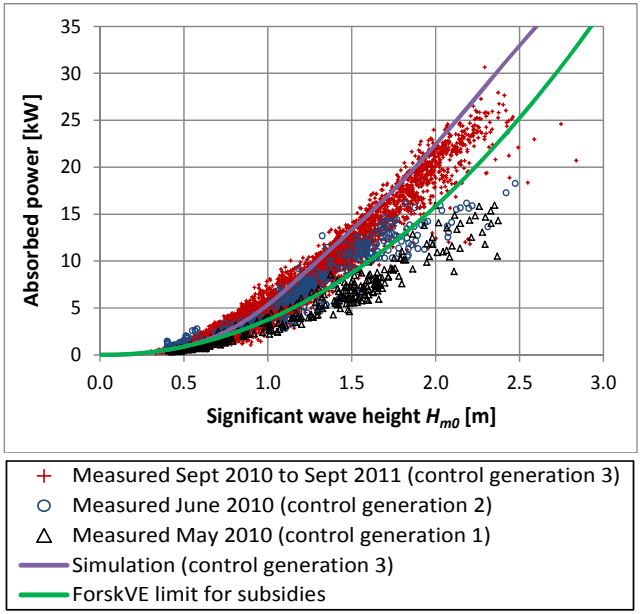
Details outside

Arms and floats

Details outside

Bearings for arms

Technology / Performances



Key features

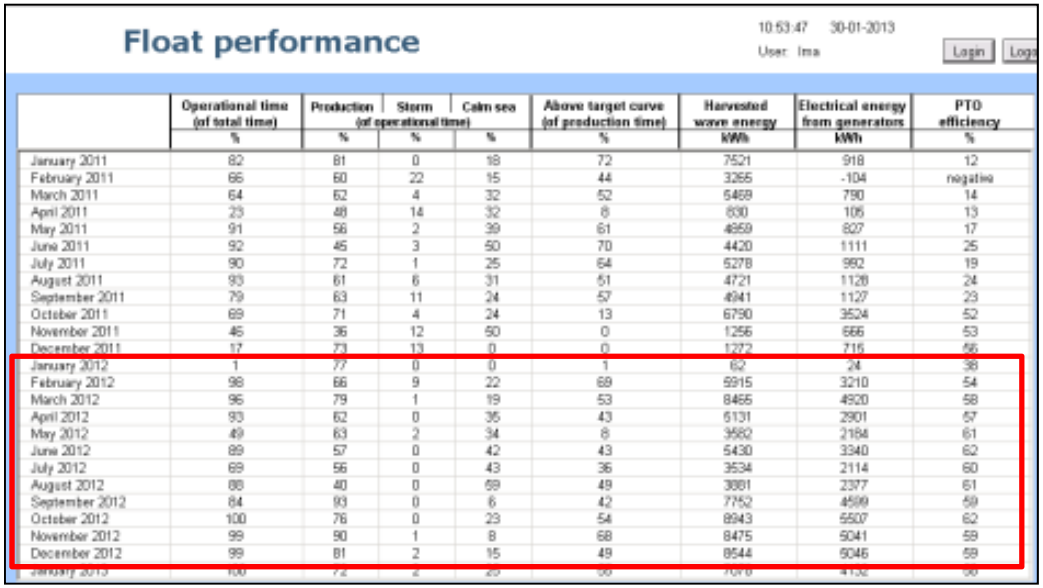
2 years
of recorded energy production

88%
of time with energy production in 2012

45 371 kWh
of produced energy in 2012

> **Energy sold to** Energinet.dk since 2010

> **Documented** performance online

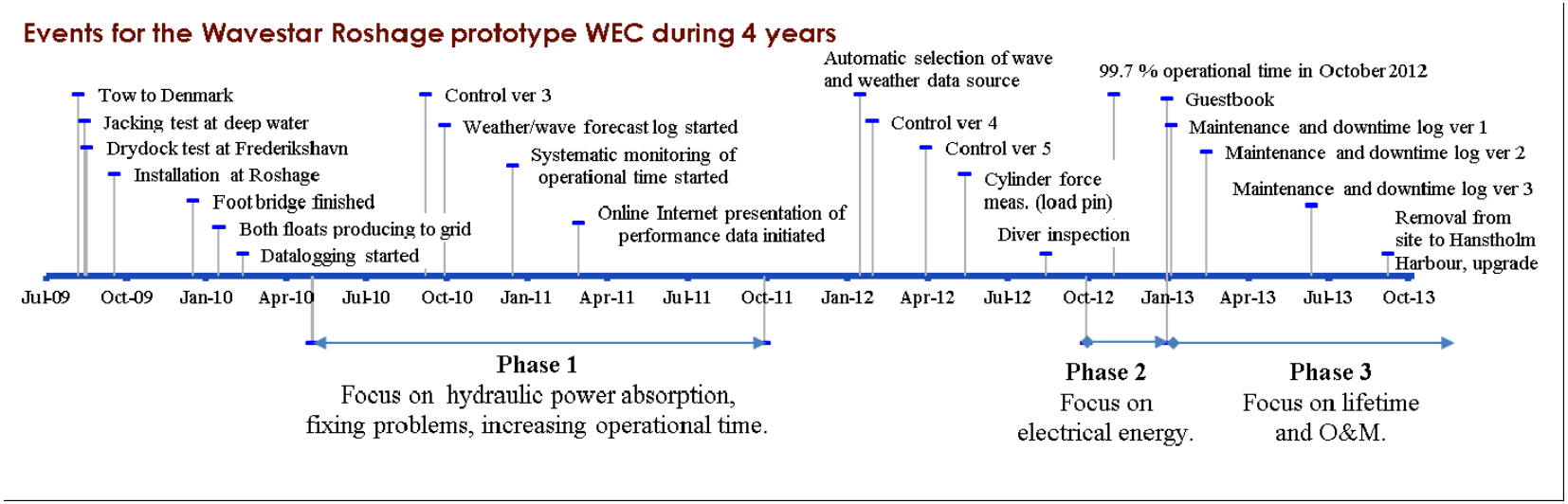


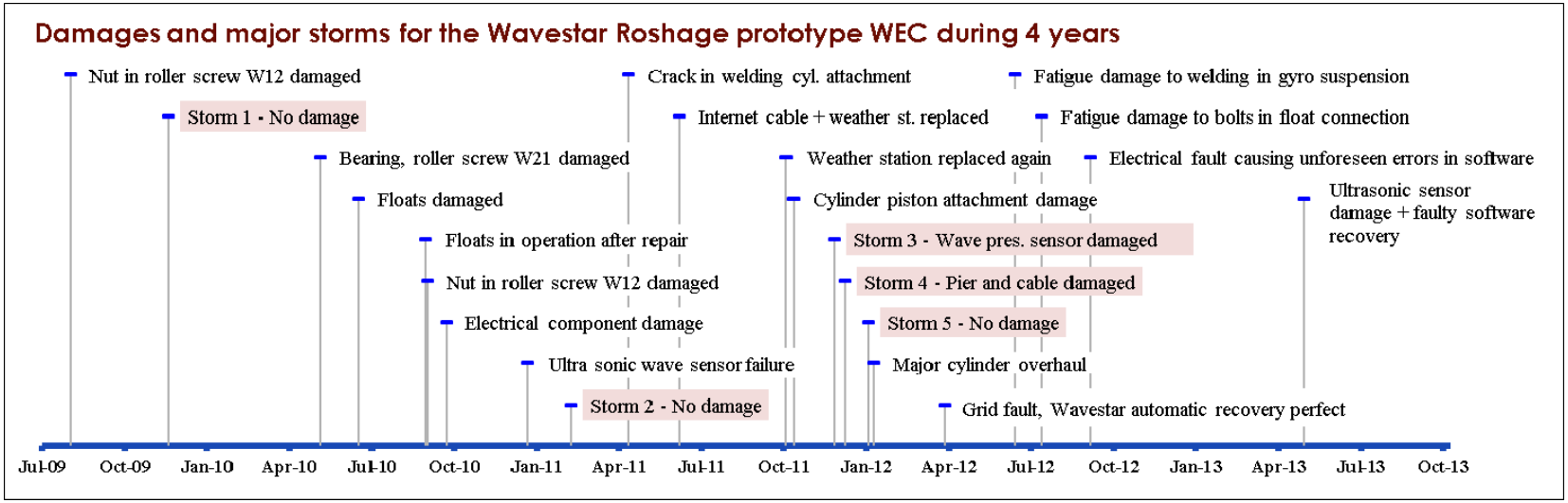
Float performance

10:53:47 30-01-2013
User: Ima
Login

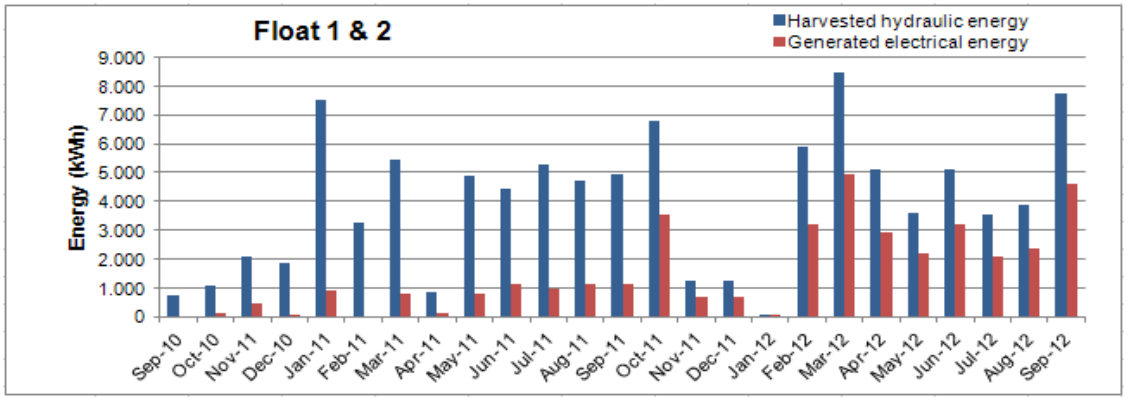
	Operational time (of total time)	Production (of operational time)	Storm	Calm sea	Above target curve (of production time)	Harvested wave energy	Electrical energy from generators	PTO efficiency
	%	%	%	%	%	kWh	kWh	%
January 2011	82	81	0	18	72	7521	918	12
February 2011	66	60	22	15	44	3265	-104	negative
March 2011	64	62	4	32	52	5469	790	14
April 2011	23	48	14	32	8	630	105	13
May 2011	91	56	2	39	61	4959	827	17
June 2011	92	45	3	50	70	4420	1111	25
July 2011	90	72	1	25	64	5278	992	19
August 2011	93	61	6	31	51	4721	1128	24
September 2011	79	63	11	24	57	4941	1127	23
October 2011	69	71	4	24	13	6790	3524	52
November 2011	46	36	12	50	0	1256	666	53
December 2011	17	73	13	0	0	1272	715	56
January 2012	1	77	0	0	1	62	24	38
February 2012	98	86	9	22	69	5915	3210	54
March 2012	96	79	1	19	53	8466	4920	58
April 2012	93	62	0	35	43	5131	2901	57
May 2012	49	63	2	34	8	3582	2184	61
June 2012	89	57	0	42	43	5430	3340	62
July 2012	69	56	0	43	36	3534	2114	60
August 2012	88	40	0	59	49	3881	2377	61
September 2012	84	93	0	6	42	7752	4599	59
October 2012	100	76	0	23	54	8943	5507	62
November 2012	99	90	1	8	68	8475	5041	59
December 2012	99	81	2	15	49	8544	5046	59

Four years of experience at real sea



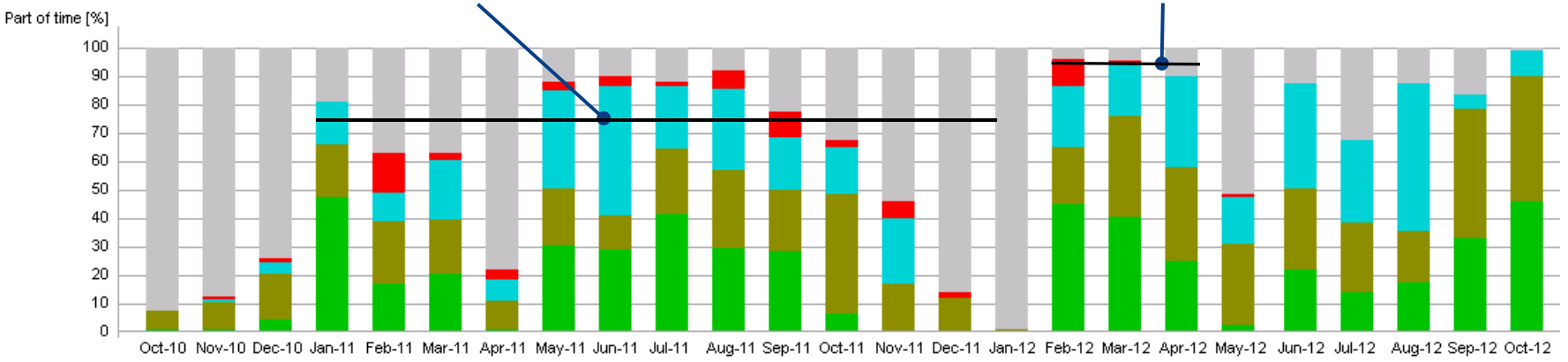


Generated energy and operational time 2010-2012



75% production time in average 2011

96% production time in average from February-April 2012



Legend:

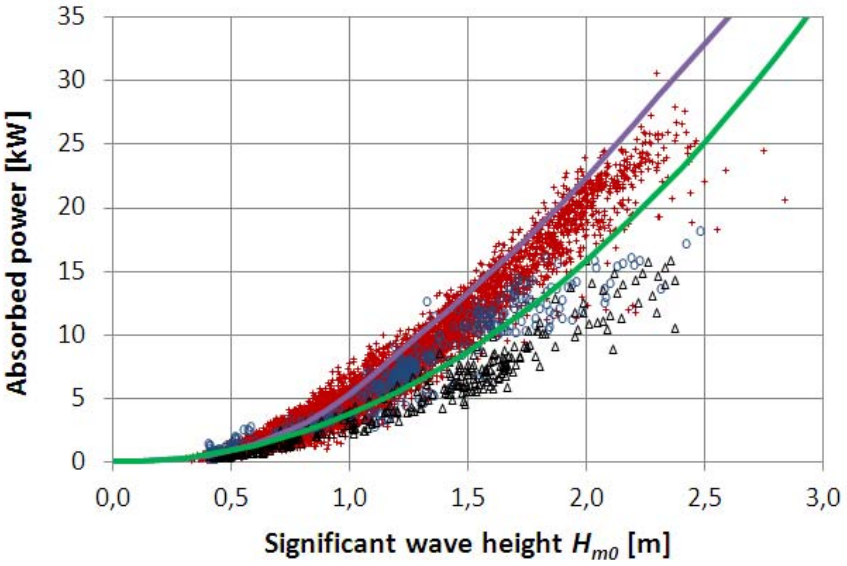
- Down time and transition states
- In storm protection
- Stopped due to calm sea
- Harvesting energy, below ForskVE curve
- Harvesting energy, above ForskVE curve

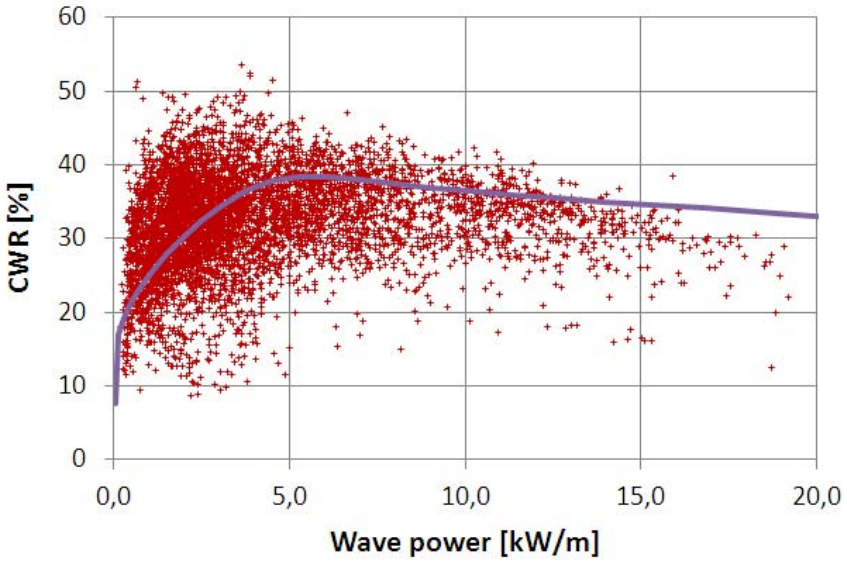
Period	Months	Hydraulic energy [MWh]	Electrical energy [MWh]	PTO efficiency [%]
Oct-10 to Sep-11	12	46.3	7.5	16.3
Oct-11 to Sep-12	12	52.8	30.4	57.6
Oct-10 to Sep-12	24	99.1	38.0	

Power measurements from the Hanstholm test unit

Measured Sept 2010 to Sept 2011 (control generation 3)
Measured June 2010 (control generation 2)
Measured May 2010 (control generation 1)
Simulation (control generation 3)
ForskVE limit for subsidies

$$CWR\,[\%] = \frac{Power\ [\mathrm{kW}]/Wave\ power\ [\mathrm{kW/m}]}{Float\ diameter\ [\mathrm{m}]} \cdot 100$$





- Red data points are 30 minute average values of harvested power from one float (hydraulic power leaving one cylinder)
- 5740 red data points are shown corresponding to 120 days of full operation
- A typical wave period for the Hanstholm location is used for the simulated curve

Removing the demonstrator from the test-site

In September 2013 the demonstrator was moved into the Hanstholm Harbour to be upgraded

https://www.youtube.com/watch?v=JYwVQwRw6Tk

Technology / Next Stages

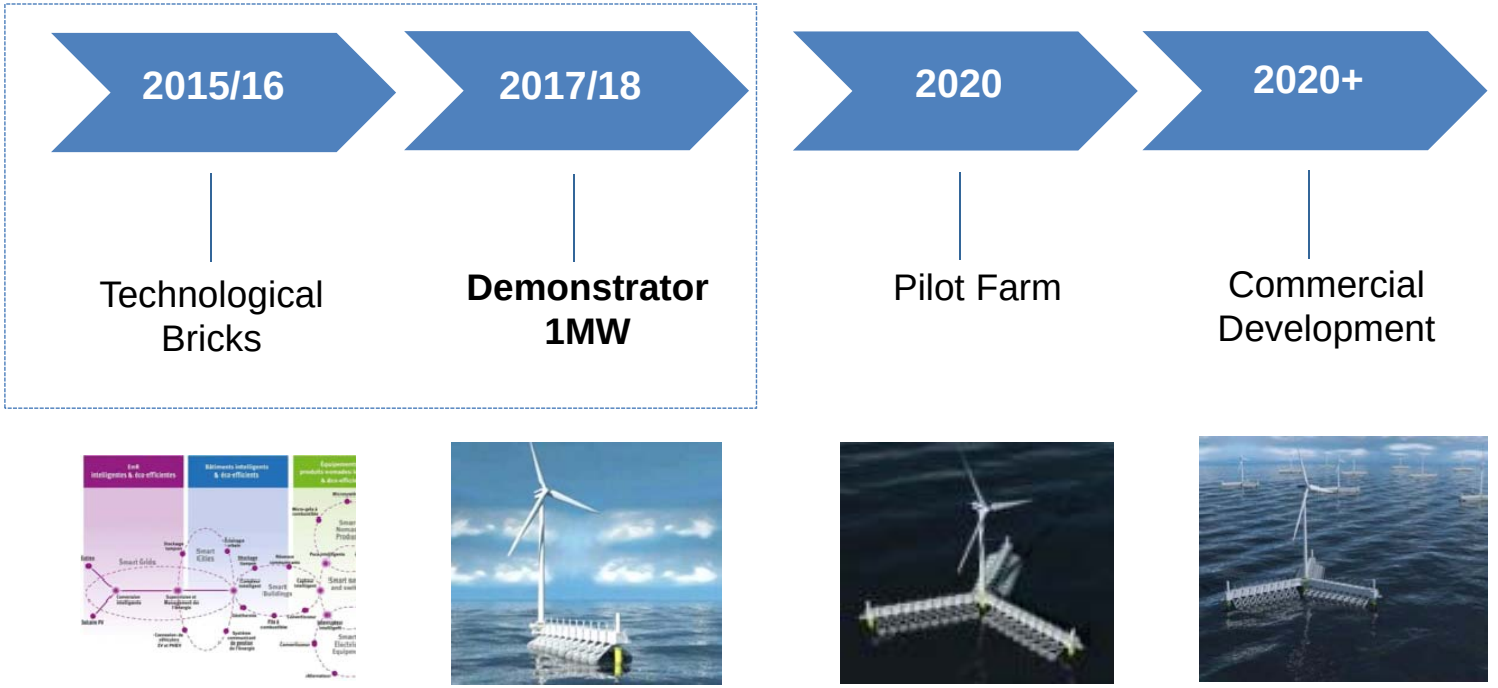
The demonstrator

- Two extra floats/arms of ø6m
- New developed PTO installed for the 4 floats
- New location at Hanstholm with higher wave resources
- Adaptation of the foundation to the new location

In September 2013 the demonstrator was moved into the harbour to be upgraded

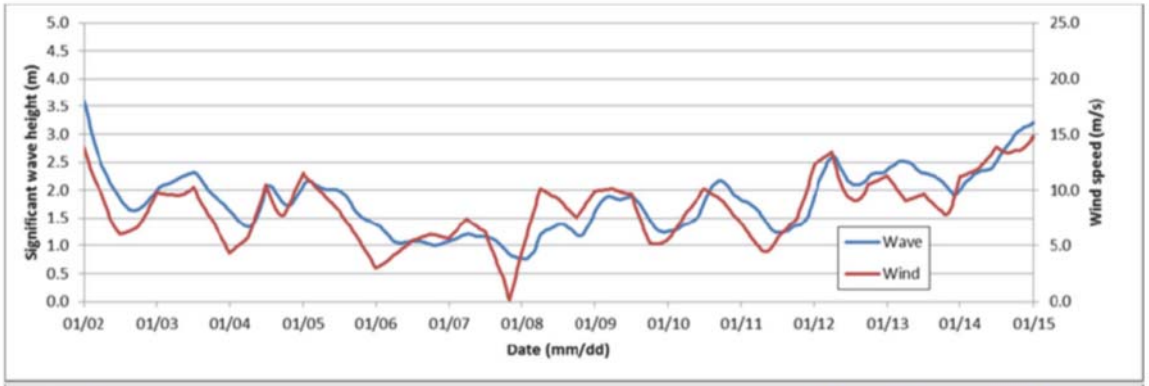
Project / Strategy

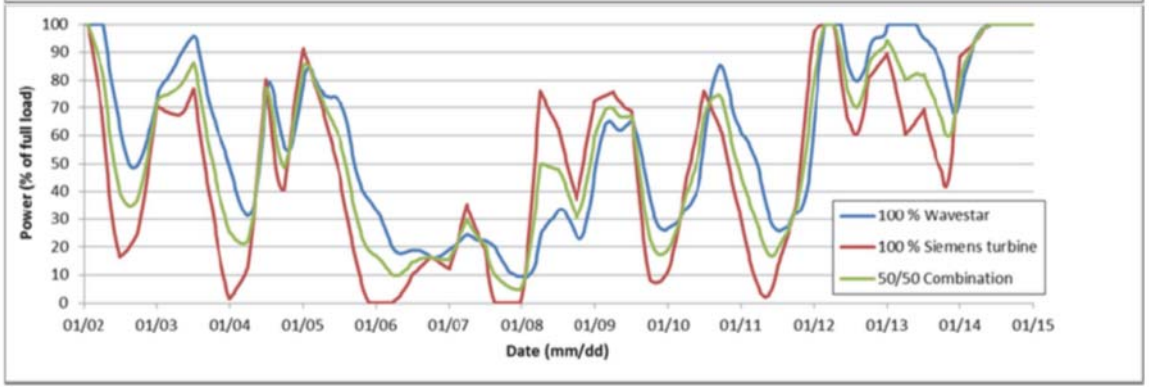
Key development steps

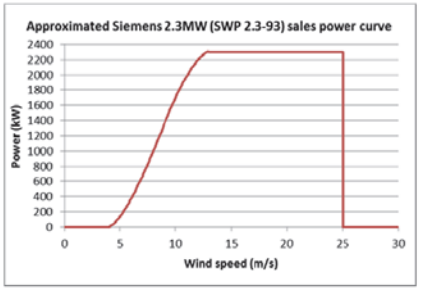


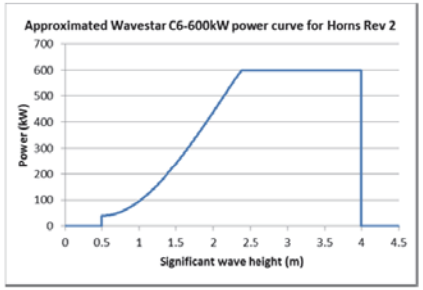
Slightly modified from:
L. Marquis, B. Kristensen, E. Sánchez
“Vision and Plans for Wavestar Development”, in Proc. EWTEC2013

Benefits from combining wind & wave energy





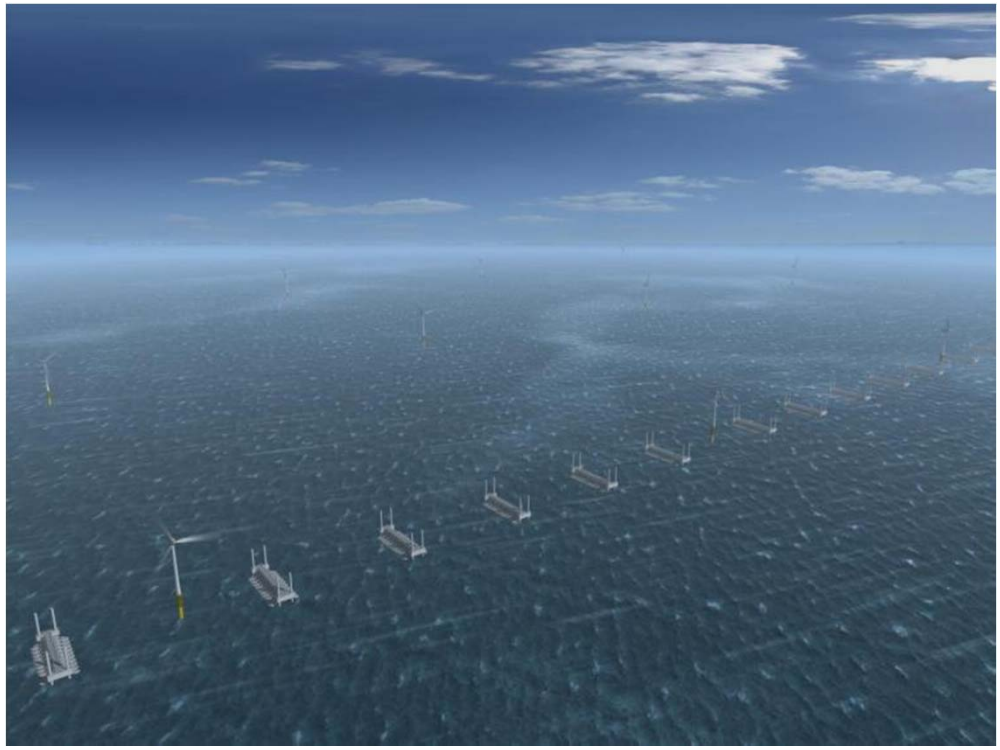




Benefits for combination

- Delay between wind & wave up to 9 hours
- Waves are more constant than winds
- More continuous power output
- Smoother power production
- Reduce the percentage time of zero production
- Reducing balancing costs

Synergies from sharing infrastructure and O&M



Synergies

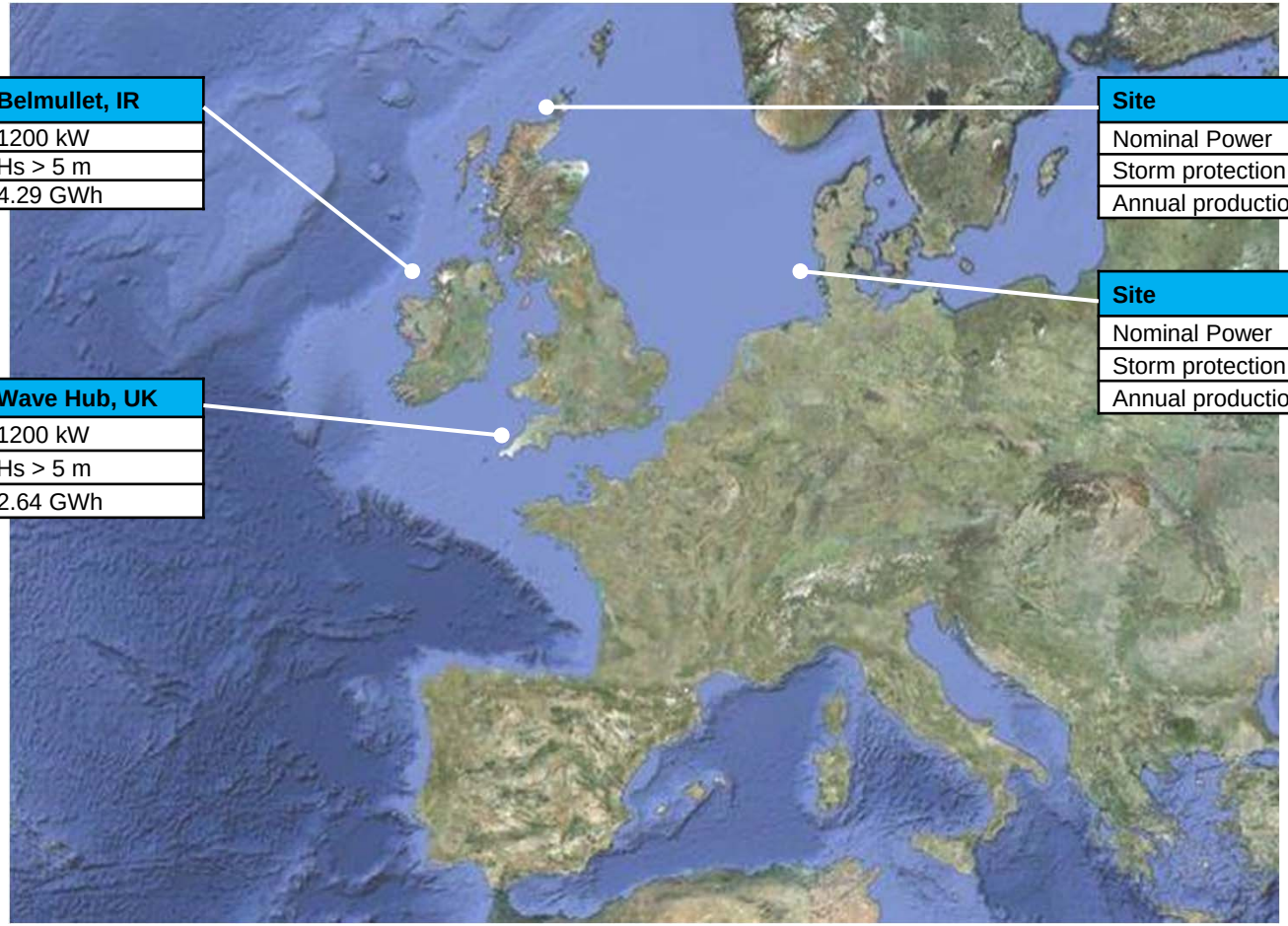
- Environmental impacts studies
- Common installation possibilities: internal cabling, transformer station, grid connection
- Operation and maintenance: sharing personnel and equipment

- Effect on wave climate in the farm (protection)
- Use of infrastructure (storage, harbour facilities, housing of staff)

Perspectives: Wavestar C6 performance at different sites in Northern Europe

Site	Belmullet, IR
Nominal Power	1200 kW
Storm protection	Hs > 5 m
Annual production	4.29 GWh

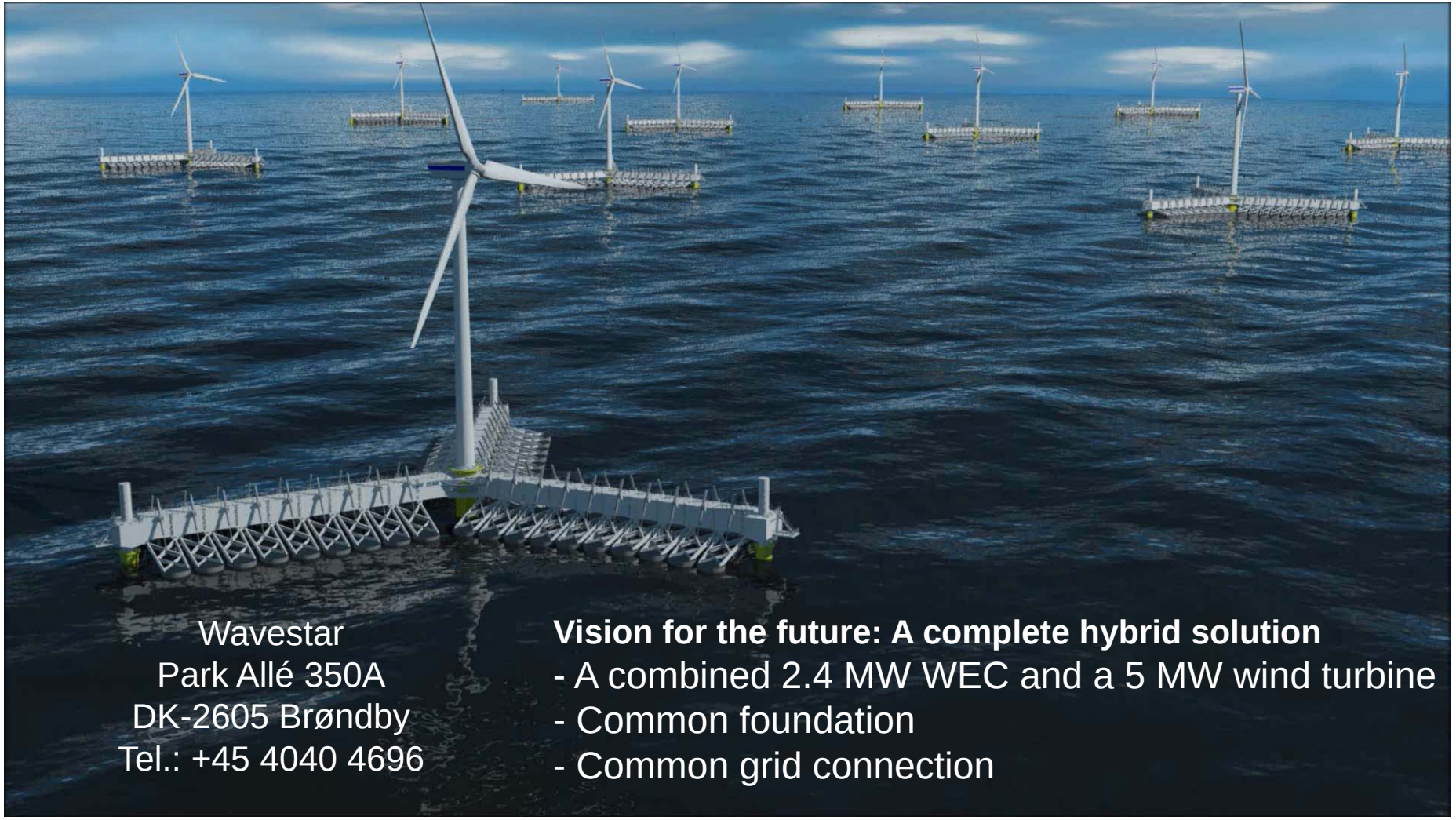
Site	Wave Hub, UK
Nominal Power	1200 kW
Storm protection	Hs > 5 m
Annual production	2.64 GWh



Site	EMEC,UK
Nominal Power	1200 kW
Storm protection	Hs > 5 m
Annual production	2.88 GWh

Site	Horns Rev 2,DK
Nominal Power	600 kW
Storm protection	Hs > 3 m
Annual production	1.41 GWh

Thank you


Wavestar
Park Allé 350A
DK-2605 Brøndby
Tel.: +45 4040 4696
Vision for the future: A complete hybrid solution
- A combined 2.4 MW WEC and a 5 MW wind turbine
- Common foundation
- Common grid connection

Some Wavestar references

Links:

Subject	Link
Wavestar Homepage	http://wavestarenergy.com/
Wavestar FaceBook	https://www.facebook.com/wavestarenergy
YouTube, “WavestarDK”	https://www.youtube.com/user/WavestarDK

EWTEC2013 conference

Title	Authors
Vision and Plans for Wavestar Development	L. Marquis, B. Kristensen, E. V. Sánchez
Comparison of Foundation Systems for Wave Energy Converters Wavestar	E. Vaitkunaite, L.B. Ibsen, B.N. Nielsen, S.D. Molina
Influence of Wave State Uncertainties on Probabilistic Reliability Assessments of Wave Energy Devices	Simon Ambühl, J. P. Kofoed, J.D. Sørensen
Increasing durability and lowering the overall cost of wave energy converters using Ultra High Performance Concrete	M.S. Jepsen, L. Damkilde, N.A. Hansen, B. Aarup
Excitation Forces on Point Absorbers Exposed to High Order Non-linear Waves	T.H. Viuff, M.T. Andersen, M.M. Kramer, M.M. Jakobsen
Optimal Discrete PTO Force for Point Absorber Wave Energy Converters in Regular Waves	A.H. Hansen, H.C. Pedersen

ICOE2012 conference

Title	Authors
Introduction of Wavestar Wave Energy Converters at the Danish offshore wind power plant Horns Rev 2	L. Marquis, M.M. Kramer, J. Kringelum, J.F. Chozas, N.E. Helstrup
Early Performance Assessment of the Electrical Output of Wavestar’s prototype	E. Vidal, R.H. Hansen, M.M. Kramer
Combined Production of a full-scale Wave Converter and a full-scale Wind Turbine – a Real Case Study	J. Fernández Chozas, M.M. Kramer, H.C. Sørensen, J.P. Kofoed
Comparison between linear numerical models and experimental results on a Wavestar point absorber	M.M. Kramer, A. Zurkinden, E. Vidal, R.H. Hansen
Reliability Assessment of Wave Energy Devices	S. Ambühl, M.M. Kramer, J.P. Kofoed, J.D. Sørensen
Assessing the structural forces in the Wavestar wave energy converter, using a coupled hydro-elastic methodology	B. Borgarino, A. Babarit, Jitendra Singh, M.M. Kramer